

**SYSTEM AND METHOD FOR BLENDING IMAGES INTO A
SINGLE IMAGE**

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BACKGROUND

[0001] Photographers, graphic artists, and others desiring to capture an image of a scene, person, device, or event can use a device such as a still camera, a video camera, a web-cam, or the like to record the desired image. At times, the field of view of the captured image is too small, either too narrow (horizontal deficiency), too short (vertical deficiency), or both, for the photographer or user. The photographer can take two or more images while panning across the desired scene and can combine the multiple images into a composite image, or panorama, of the entire scene.

[0002] The resultant images can be cut and pasted together, whether manually, electronically, or digitally to combine the separate images or pictures into a single image. However, slight variations in the separate images can cause the cut and paste single image to appear as a mosaic instead of a contiguous, single image of the scene. The variations in the separate images can be the result of differences in projection angle and/or motion within the scene between the times the images were captured.

[0003] Various techniques have been proposed for blending images together to form a single image. One such method for blending overlapping images together utilizes Laplacian and Gaussian pyramids. An algorithm-based technique for blending overlapping images together can also be used.

[0004] Additional techniques have been disclosed that utilize both blending and warping to process images. For example, a blended image can be distorted with warping. Alternately, an image can first be morphed and then the colors of the warped image can be blended.

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SUMMARY

[0005] Exemplary embodiments are directed to a method and system for blending images into a single image, including selecting two images having overlapping content; dividing the two images into strips; selecting a strip in each of
5 the two images where the two images overlap each other; determining differences between the overlapping two strips; determining a line through the overlapping strips where the differences between the overlapping strips are minimized; and blending the two images together along the minimized line to create a single image.

[0006] An additional embodiment is directed toward a method for blending
10 two images into a single image, including dividing two images into strips along a common plane; selecting a strip in each image where the two images overlap; determining a line through the overlapping strips where differences between the overlapping strips are minimized; blending the two images along the determined minimized line to create a single image; and warping the single image to minimize
15 blurring along the blending line.

[0007] Alternative embodiments provide for a computer-based system for blending images into a single image, including a computer configured to divide two images having overlapping content into strips; select a strip in each of the two images where the two images overlap each other; determine pixel difference values
20 between the overlapping two strips; determine a line through the overlapping strips where the sum of the pixel difference values between the overlapping strips are minimized; and blend the two images together along the minimized line to create a single image.

[0008] A further embodiment is directed to a system for blending images
25 into a single image, including means for dividing two images having overlapping content into strips in at least one region of overlap; means for calculating difference values between the pixels of the two images in the at least one region of overlap; means for determining a cut line through the two images where the difference values

are minimized; and means for blending the two images along the cut line to create a single image.

5 [0009] Yet a further embodiment is directed to a system for blending images into a single image, including a first computing module dividing two images having overlapping content into strips in at least one region of overlap; a second computing module calculating difference values between the pixels of the two images in the at least one region of overlap; a third computing module determining a cut line through the two images where the difference values are minimized; and a fourth computing module blending the two images along the cut line to create a blended single image.

10 [00010] Another embodiment provides for a computer readable medium encoded with software for blending images into a single image, wherein the software is provided for selecting two images having overlapping content; dividing the two images into strips where the two images overlap each other; selecting a strip in each of the two images; determining the differences between the overlapping two strips; 15 determining a line through the overlapping strips where the differences between the overlapping strips are minimized; and blending the two images together along the minimized line to create a single image.

BRIEF DESCRIPTION OF THE DRAWINGS

20 [00011] The accompanying drawings provide visual representations which will be used to more fully describe the representative embodiments disclosed herein and can be used by those skilled in the art to better understand them and their inherent advantages. In these drawings, like reference numerals identify corresponding elements, and:

25 [00012] Figure 1 shows a component diagram of a system for blending images into a single image in accordance with an exemplary embodiment of the invention.

[00013] Figure 2 shows a block flow chart of an exemplary method for blending images into a single image.

[00014] Figure 3 shows a block flow chart of an exemplary method for determining a cut line for blending the images into a smooth single image.

[00015] Figure 4 shows two images of the same beach scene, with the images differing in time and field of view.

5 [00016] Figure 5, consisting of Figures 5A, 5B, and 5C, shows two images of the same action scene, with the images differing in time.

[00017] Figure 6, consisting of Figures 6A, 6B, and 6C, shows a progression of gray scale image processing of a pair of overlapping strips of images.

[00018] Figure 7, consisting of Figures 7A, 7B, 7C, 7D, 7E, and 7F, shows
10 iterative processing for determining a cut line between two overlapping image strips.

[00019] Figure 8 shows areas of blurred matching along the cut line determined between two overlapping image strips.

[00020] Figure 9, consisting of Figures 9A and 9B, shows warping of an image by Gaussian warping.

15 [00021] Figure 10, consisting of Figures 10A and 10B, shows application of warping to smooth a blended image.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[00022] Referring initially to Figure 1, there is illustrated a computer-based
20 system for blending images into a single image according to an exemplary embodiment. Exemplary embodiments can be implemented on a computer having a processor, including a personal computer, a network server, a mainframe computer, and the like. Those of ordinary skill in the art will appreciate that the use of the term, "blending," is intended to broadly represent the combining of multiple images
25 into a single image without limitation. The terms of "tiling" and "stitching" are also in use in the art to represent the combining of multiple pictures into a single image, and the term "blending" is intended to encompass such terms. Further, the term, "single image," is intended to broadly encompass an image resulting from combining

of two or more images together. Terms included in single image include mosaic, composite, and panoramic images.

[00023] The system of Figure 1 shows a recording device such as a camera 102, including a digital camera, configured to record an image of a scene, event, person, device, or any such desired view. Alternatively, any number of image recording devices, such as a video camera 104 or a web-cam 106, can be used to capture an image. The resultant recorded image can be stored on such media as cassette tapes 107 and/or CD's 108. For the convenience of processing the images, the recorded images can also be stored in a memory or on a storage device 110 to be subsequently processed by a computer 100 comprising one or more processors 112.

[00024] Exemplary embodiments are compatible with various networks 114, including the Internet, whereby the images can be downloaded across the network for processing on the computer 100. The resultant single images can be uploaded across the network 114 for subsequent storage and/or browsing by a user who is situated remotely from the computer 100.

[00025] One or more images are input to a processor 112 in a computer 100 according to exemplary embodiments. Means for receiving the images for processing by the computer 100 can include any of the recording and storage devices discussed above and any input device coupled to the computer 100 for the reception of images. The computer 100 and the devices coupled to the computer 100 as shown in Figure 1 are means that can be configured to receive and blend the images into a single image or view according to exemplary embodiments. In particular, the processor 112 in the computer 100 can be a single processor or can be multiple processors, such as first, second, and third processors, each processor adapted by software or instructions of exemplary embodiments for performing blending of images into a single image according to exemplary embodiments. The multiple processors 112 can be integrated within the computer 100 or can be configured in separate computers which are not shown in Figure 1. The processor(s) 112 can

comprise one or more computing modules, such as first, second, or third computing modules, to perform the steps shown in Figure 2.

[00026] These processor(s) and the computing modules and/or software guiding them can comprise the means by which the computer 100 can select a strip
5 in each of two images where the images overlap each other and can determine a cut line through the two strips where the images can be joined to form a single image. For example, separate means in the form of software modules within the computer 100 can control the processor(s) 112 for selecting the best strip in each image where the images overlap and for blending the images along a cut line in the strips for
10 creating a single image of a scene. The computer 100 can include a computer-readable medium encoded with software or instructions for controlling and directing processing on the computer 100 for directing blending of images into a single image.

[00027] The computer 100 can include a display, graphical user interface, personal computer 116 or the like for controlling the processing of the classification,
15 for viewing the classification results on a monitor 120, and/or for listening to all or a portion of sound signals associated with the images over the speakers 118. One or more images are input to the computer 100 from a source of images as captured by one or more still cameras 102, video cameras 104, or the like and/or from a prior recording of a scene or event stored on a medium such as a tape 107 or CD 108.

20 While Figure 1 shows the images from the still camera 102, the video camera 104, the tape 107, and the CD 108 being stored on an image storage medium 110 prior to being input to the computer 100 for processing, the images can also be input to the computer 100 directly from any of these devices without detracting from the features of exemplary embodiments. The media upon which the images is recorded can be
25 any known analog or digital media and can include transmission of the images from the site of the event to the site of the image storage 110 and/or the computer 100.

[00028] Embodiments can also be implemented within the capture/recording devices 102, 104, and 106 themselves so that the images can be blended concurrently with, or shortly after, the images being recorded. Further, exemplary

embodiments of the image blending system can be implemented in electronic devices other than the computer 100 without detracting from the features of the system. For example, and not limitation, embodiments can be implemented in one or more components of an image projection system, such as in a CD/VCD/DVD
5 player, a VCR recorder/player, etc. In such configurations, embodiments of the image blending system can blend images prior to or concurrent with the display of the single image(s).

[00029] The computer 100 optionally accepts as parameters one or more variables for controlling the processing of exemplary embodiments. As will be
10 explained in more detail below, exemplary embodiments can apply one or more control parameters to guide the image blending processing to customize the blending and warping of the images to create single images according to the preferences of a particular user. Parameters for controlling the blending and warping processes can be retained on and accessed from storage 122. For example, a user can select, by
15 means of the computer or graphical user interface 116, parameters for establishing how smoothly, or seamlessly, exemplary embodiments should blend two images together to produce a single image of a scene. These control parameters can be input through a user interface, such as the computer 116 or can be input from a storage device 112, memory of the computer 100, or from alternative storage media without
20 detracting from the features of exemplary embodiments. Single images blended by exemplary embodiments can be written into a storage media 124 in the forms of files, catalogs, libraries, and/or databases in a sequential and/or hierarchical format. The processor 112 operating under control of exemplary embodiments can output the results of the image blending process, including printed images, summaries, and
25 statistics, to a printer 130.

[00030] The functionality of an embodiment for automatically blending images to create a single image can be shown with the following exemplary flow description:

Blending Images into a Single Image:

Select two images for blending

Dividing the two images into strips along a common plane

Select a strip in each of the two images where the images overlap

5 Determine a line through the two strips where the differences between the two images is minimized

Blend the two images along the determined minimized line

Repeat the process until all images are blended into a single image

10 [00031] Referring now to Figures 1, 2, and 4, a description of an exemplary embodiment of a system for blending images into a single image will be presented. An overview of the image blending process is shown in Figure 2, and a pair of exemplary images to be blended is shown in Figure 4. At step 200 two images, 400 and 402, of an exemplary beach scene are selected from image storage 110 for
15 blending into a single view of the scene. The two images show at least part of a common scene, with at least partial scene overlap between the two images. The images of the scene can differ from each other in such areas as the scope or field of image coverage, the time the images were recorded, the location from which the images were captured, the devices capturing the images, the settings of the camera(s)
20 recording the scene, the lighting of the scene, the shadows in the scene, and/or the background of the scene. Figure 4 shows two beach scene images, 400 and 402, that were taken at slightly different times and with different width of field settings on the camera, with image 402 having been taken at a slightly later time and at a center of image somewhat to the left from the timing and orientation of image 400. At step
25 202, each image is divided into strips along a common plane. The vertical lines in each image represent exemplary strips that can be drawn or established to divide the images. The strips can be limited to all or a portion of where the images overlap. In the exemplary case of the images of Figure 4, strips have been drawn in the general center portion of the images 400 and 402. The number and/or width of the strips can

be selected by the user with a parameter or can be established by the image blending system. Additionally, the system can compare the differences between the two images such as pixel by pixel or by intensity and can establish an area of overlap for creating strips where the differences between the images are less than a

5 predetermined or selected threshold. At least one strip is created in each image; and the strips are created such that for each strip in one image, there is a corresponding strip in the other image showing approximately the same scene portion. While Figure 4 shows strips aligned along a vertical plane, any common plane can be utilized to divide the two images, depending on the orientation of the images.

10 [00032] One strip from each of the two images is selected in step 204 where the images overlap. In Figure 4, strip 404 has been selected from image 400, and strip 406 has been selected from image 402. The criteria for the selection of a strip in each of the images is to find an area in each of the images where the two respective image scenes overlap each other and where the best match, or the minimal error, between the two image scenes is found. One technique by which exemplary

15 embodiments can select overlapping and matching strips from each image is by calculating the mean squared error or difference between paired strips of the two images according to the following mean squared difference algorithm:

20 [00033]
$$(R_1 - R_2)^2 + (G_1 - G_2)^2 + (B_1 - B_2)^2 = \text{Diff Value}$$

[00034] A relative difference value for determining the image differences between strip₁ (404) of image₁ (400) and strip₂ (406) of image₂ (402) is calculated by first finding the sum of the squared differences of each of the red, green, and blue

25 (RGB) color pixel values for each pair of corresponding pixels between the two strips and then adding together all such difference values for that pair of strips. The difference value can also be viewed as a mean squared error value of the degree of mismatch between the two images at their respective strips. Each strip is selected to have the same number of pixels so the mean squared color difference algorithm can

be applied throughout each strip. Under this technique, the differences in the red, green, and blue pixel values for each pair of corresponding pixels in the two strips are squared and summed to produce the image pixel difference value representing the measure of difference between the two image strips, such as 404 and 406. By
5 iteratively calculating the mean squared difference value between selected strips from the two images, exemplary embodiments can select a pair of strips, one from each image 400 and 402, where the image difference between the two strips is minimized and, accordingly, the overlap between the two images is the closest match at the selected strips. As can be seen by comparing strips 404 and 406, the strip of
10 the images shown by these strips is very similar, although not identical, and is representative of an area within the image scene where the two images, 400 and 402, overlap. While the mean squared pixel difference value has been disclosed for selecting overlapping image strips 404 and 406, exemplary embodiments are not so limited, and any known technique for matching and/or comparing images can be
15 utilized to select a strip from each of two overlapping images where the difference or mismatch in the overlap is minimized. For example, a pixel by pixel intensity or luminescent comparison between two sample strips can be utilized to select two overlapping and matching strips. The width of the strips can be reduced by the user to reduce the computational time and resources to perform the steps of strip
20 selection. Similarly, the number of strips and the size of the image region to be divided into strips can be limited to control processing time and resources.

[00035] Referring now to Figure 5, there is shown at Figures 5A and 5C two images, 500 and 502, of a boy in the process of walking forward. Image 502 was taken slightly later in time from image 500 and with a center of field slightly to the
25 right of the center of image 500. Figure 5B shows two strips, 504 and 506, positioned here side by side for the sake of comparison. Strip 504 has been selected from image 500 of Figure 5A, and strip 506 has been selected from image 502 of Figure 5C by exemplary embodiments as an overlap area of best match between

images 500 and 502 for combining image 500 and image 502 into a single image of the boy walking.

[00036] Referring now to Figure 6, the selected strips, 504 and 506, of Figure 5B are now shown in Figure 6A. The next step in the method for blending two
5 images into a single image, step 206, is applying an image matching or comparison algorithm to the two strips 504 and 506 to determine the pixel differences between the overlapping two strips. In an exemplary embodiment, the pixel differences between the two strips can be determined, pixel by corresponding pixel, by a mean squared difference algorithm in a manner similar to the calculation of the pixel
10 difference values for selecting the overlapping strips. Alternately, the difference between the overlapping strips can be calculated based on pixel intensity or luminescent values. Once the difference values between the pairs of corresponding pixels in the strips is determined, the pixel to pixel difference values between the two strips can be converted to shades of gray for each pair of pixels, one from each
15 strip at a given pixel location, and represented graphically as a gray scale difference image 600 as shown in Figure 6B. In the exemplary gray scale difference image of Figure 6B, dark areas represent areas between the two strips 504 and 506 that match closely, and the light and bright tones represent areas of mismatch between the strips. For example, the cheek of the two strips 504 and 506 appears as a dark area
20 604 in the gray scale difference image 600 whereas the ear of the boy shows as a bright area 602 of mismatch between the two strips 504 and 506 and, correspondingly, between the two images 500 and 502. Figure 6C shows a blurred image 606 of mismatch between the strips 500 and 502 where the degree of mismatch between the pixels of each image is represented as varying degrees of
25 brightness, thereby blurring the overlapped image.

[00037] At step 208, represented by the figures of Figure 7, a line is determined through the combined image of the strips where the differences between the strips is minimized. It will be along this line that the two strips, and thus the two images, will be cut to blend the images into a single image at step 210. Figure 7A

will be recognized as a slightly enlarged version of Figure 6C, representing a gray scale image of the differences between the two image strips 504 and 506. Because the darker portions of image 606 represent areas of closer match between the strips 504 and 506, exemplary embodiments will determine a line through the darker areas of the image 606 as the areas of greatest match or alignment between the images where the two images can be blended together for a smooth fit. Figures 7B through 7F show the iterative process of growing the first and second regions, from left and right respectively, to achieve a cut line 704 between the images 500 and 502 for blending them into a single image. The method for determining the cut line is shown in the block flow diagram of Figure 3.

[00038] The first step, step 300, for determining a line where the images should be cut for being combined into a single image is to calculate a difference value for each pixel pair between the two overlapping strips. In some embodiments, as discussed above, this step has already been completed during the process of determining the two overlapping strips to be selected for finding the best matching strip between the two images. For example, a mean squared difference algorithm can be used to determine a difference value between each pair of pixels in the corresponding overlapping strips 504 and 506. Next, at step 302, the pixels of the difference image shown in Figure 7A are sorted in descending order of difference value, from the pixel of largest difference value between the strips to the pixel of smallest difference value, or closest match.

[00039] Figure 7B shows a blank region map 700 that has the same number of pixels as the overlap region as represented by Figure 7A. At step 304, all pixels that lie on the left edge of the difference image 606 are assigned or mapped to a first region 701, and all pixels that lie on the right edge of the difference image 606 are assigned to a second region 702. Starting with the sorted pixel of the greatest difference value and proceeding, pixel by pixel, to the pixel of the smallest difference value of the gray scale image 606 of Figure 7A, all the remaining

unassigned pixels of the difference image 606 are mapped by adjacency to either the first region 701 or the second region 702 of the region map 700 as follows.

[00040] At step 306, the next unassigned pixel with the greatest difference value is processed and mapped to the region 700 according to the adjacency of the pixel to a region. If the pixel is adjacent to region 701 and is not adjacent to any other region, the pixel is assigned, or mapped, to region 701. If the pixel is adjacent to region 702 and is not adjacent to any other region, the pixel is assigned to region 702. If the pixel is adjacent to both regions 701 and 702, the pixel is arbitrarily assigned to either region 701 or 702. For example, the dual adjacent pixels can alternately be assigned first to region 701 and next to region 702. If the pixel is adjacent to no other regions, a new region 706 is created within 700; and the pixel is assigned to the new region 706. If the pixel is not adjacent to either region 701 or region 702 but is adjacent to one of the aforementioned new regions 706, the pixel is assigned to the adjacent new region 706. Further, if the pixel is adjacent to two or more new regions 706, those regions are combined into a single new region 706.

[00041] If the pixel is adjacent to region 701 and is also adjacent to one or more new regions 706, then the pixel is assigned to region 701; and all the pixels in the other adjacent regions 706 are also assigned to region 701. Correspondingly, if the pixel is adjacent to region 702 and is also adjacent to one or more new regions 706, then the pixel is assigned to region 702; and all the pixels in the other adjacent regions 706 are also assigned to region 702. If the pixel is adjacent to both regions 701 and 702 and is also adjacent to one or more new other regions 706, then the pixel is arbitrarily assigned to either region 701 or 702, as discussed above. In this situation, all the pixels in the other adjacent regions 706 are assigned to the same region, 701 or 702, to which the pixel was assigned.

[00042] All remaining pixels in the difference image 606 of Figure 7A are processed in a similar manner, as shown in the progression of the region map 700 from Figure 7B to Figure 7F, until all the pixels are assigned to the first and second regions 701 and 702. In Figure 7C, for example, the first region 701 and the second

region 702 are shown to have grown in size from the respective first and second regions as shown in Figure 7B as more of the pixels of the difference image 606 are mapped to the region map 700. Correspondingly, as more pixels of the difference image 606 are mapped to the region map 700, the first and second regions 701 and 702 grow from the left and right, respectively, as shown in Figure 7D. Areas 706 of Figure 7D represent those mapped "new other regions" of pixels that are not yet adjacent to or part of any of the first region 701 or the second region 702.

[00043] The mapping of all of the pixels of the difference image 606 produces the image of Figure 7F with a completed first region 701 and a completed second region 702. The boundary 704 between the left and right regions represents a single line of pixels that are adjacent to both the first and second regions and represents the cut line to be made through the image strips 504 and 506 where the differences in the overlapping strips are minimized. This cut line also becomes the line or the template by which the two corresponding images 500 and 502 of the boy walking are cut at step 310. The two now cut images 500 and 502 are blended together at step 312 along their common, minimized cut line to blend the images into a single image of the boy walking. By use of the term, "cut," exemplary embodiments can, for example and not limitation, digitally divide the two images 500 and 502 along the common cut line, saving the respective left and right sides of images 500 and 502, and combining the saved sides into a blended single image.

[00044] In another exemplary embodiment, a plurality of images exceeding two images can be blended into a single image. In this embodiment, two images at a time are selected for blending into a single image. The resultant single image is then reinput to the image blending process as one of two selected images, with a new, unprocessed image constituting the second selected image. This process continues until all images comprising the scene, event, or the like have been processed, resulting in a final single image blended from the plurality of images. In like manner, separate frames of a video sequence can be blended into a single image of the video.

[00045] In an alternate embodiment, represented by Figures 8, 9, and 10, the line along which the images have been cut and blended can be further smoothed to produce a better seam between the images in the resultant single image. In this embodiment, a Gaussian pyramid and/or spatial warping can be applied to the pixels
 5 in the area of the cut to improve the fit between the images along the cut. For example, the difference values of the pixels along the cut line 704 can be compared against a predetermined threshold of image match, optionally selected by the user from control parameter storage 122, to determine whether the cut line produces a sufficiently smooth blend line between the two images. To determine the degree of
 10 match along the cut line 704, the mean squared RGB difference value for each of the pixels along the cut line 704 can be compared against a numeric difference value. If the difference value for a pixel exceeds the selected threshold, then the image areas along the cut line at that pixel location can be further processed to improve the match between the images to produce a smoother blending of the images. The
 15 representative areas 800 of Figure 8 show exemplary areas where the difference value for the pixels exceeds the threshold, with the resultant blended single image being blurred in these mismatched areas.

[00046] To improve the fit between the two images along the cut line, the two images can be warped, or spatially bent or morphed, in the areas of disagreement to
 20 better align the pixels in the mismatch areas. Referring to Figure 9, the original grid of pixels for the blended image at an area of disagreement is shown by 900. By warping the grid to the left along a horizontal plane by the magnitude of a Gaussian function, the distorted grid at 902 is produced. Application of this warping process on an exemplary image is shown in Figure 10. Here, Figure 10A shows the detail of
 25 the boy's head from the blended image from the original two images 500 and 502 of Figure 5. Even though the two images have been blended together to form a composite image along a cut line of minimal disagreement, some details, such as the boy's ear, are distorted, as shown in Figure 10A at 1000. After Gaussian warping,

the ear 1002 is still distorted in Figure 10B, but the double image has been eliminated.

[00047] For each area of disagreement along the cut line that exceeds a threshold, exemplary embodiments can iteratively warp the images in the areas of disagreement along a plurality of common planes by a plurality of magnitude of warp until the minimum pixel disagreement is found. For example, the warping shown in Figure 10 has warped the two images along a horizontal plane to produce the warped image in Figure 10B. In exemplary embodiments, eight different planes of warping can be sampled to find the orientation of distortion that produces the best match between the two images along the cut line. For each plane of warping, a plurality of degrees or magnitudes of warping can be applied to find the best fit between the images, thereby producing a smoothly blended single image. The direction of warping can also be variable to find the best fit. For example, the pixels of image 500 could be warped to the right in an area 800 of mismatch, while the pixels of image 502 could be warped to the left in the corresponding area 800 of mismatch to find the best fit.

[00048] Although exemplary embodiments of the present invention have been shown and described, it will be appreciated by those skilled in the art that changes may be made in these embodiments without departing from the principle and spirit of the invention, the scope of which is defined in the appended claims and their equivalents.